

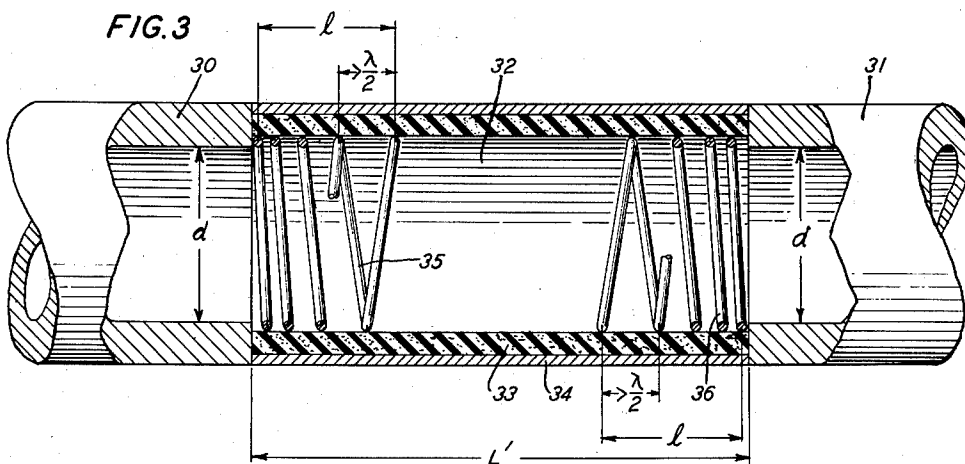
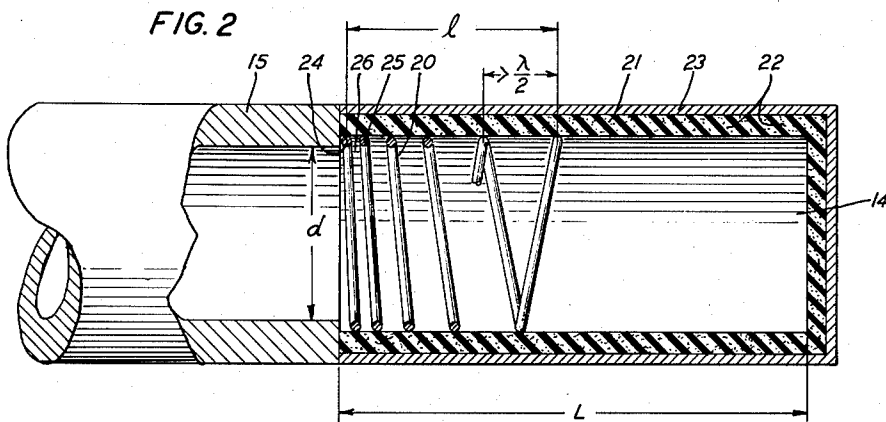
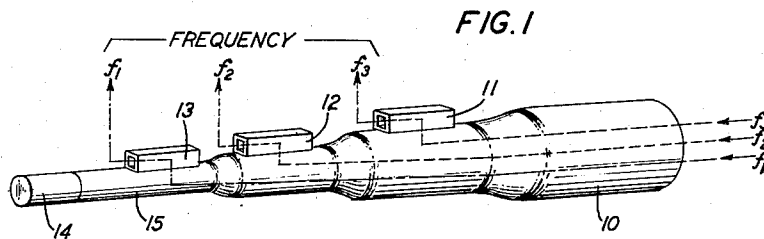
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ELECTROMAGNETIC WAVE ATTENUATOR

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ELECTROMAGNETIC WAVE ATTENUATOR

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6 Claims. (Cl. 333—81)

This invention relates to normal mode matched attenuators for use with cylindrical waveguides transmitting circular electric wave energy.

In the transmission of electromagnetic wave energy through a hollow conductive pipe or other waveguide, it is well known that the energy can propagate in one or more transmission modes, or characteristic field configurations, depending upon the cross-sectional size and shape of the particular guide and the operating frequency, and that the larger cross-section of the guide is made the greater is the number of modes in which the energy can propagate at a given operating frequency. Very generally it is desired to confine propagation of the energy to one particular mode, chosen because its propagation characteristics are favorable for the particular application involved. If the desired mode happens to be the so-called dominant mode, it is feasible to restrict the cross-sectional dimensions of the guide so that no modes other than the dominant mode can be sustained therein. This expedient is not available however, if the desired mode is not the dominant mode or if a guide of large cross-section is prescribed in order, for example, that advantage may be taken of its relatively low attenuation. This is particularly true of systems employing the TE_{01} circular electric mode. As is well known, the propagation of microwave energy in the form of the TE_{01} mode in circular waveguides is ideally suited for the long distance transmission of high frequency wide band signals since the attenuation characteristic of this transmission mode, unlike that of other modes, decreases with increasing frequency. However, since the TE_{01} mode is not the dominant mode supported in a circular waveguide, energy may be lost to other modes that are also capable of transmission therein.

In an ideal waveguide which is perfectly uniform and conducting, the propagation of TE_{01} waves therethrough is undisturbed, but changes in the propagation constants of the guide may excite waves of other modes and produce unwanted reflections. Such changes in the propagation constants of the line may occur, for example, at repeater stations in line terminations following a series of channel dropping filters or in attenuator sections which might be used in experimental work. The effect of introducing a lossy section of waveguide for either of the above-mentioned purposes is to generate higher order circular electric modes and, in some instances, non-circular modes. Reflections of these spurious modes from a line terminating section will produce deleterious effects as will the reflection or transmission of these unwanted modes from an attenuator.

It is, therefore, an object of this invention to couple, with minimum mode conversion, circular electric mode wave energy in a multimode system from one transmission medium to another having different transmission constants.

It is an additional object of this invention to achieve such coupling over a broad frequency band.

In accordance with a specific embodiment of the in-

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vention, the high impedance wall of a lossy section of waveguide, being used either as an attenuator or line termination, is gradually exposed to the circular electric wave energy by means of a conductive tapered helical member. The pitch of the helix, which is tight wound at the junction of the copper pipe and lossy guide, gradually increases until the spacing between turns is approximately one-half wavelength of the lowest frequency to be transmitted. At this spacing the helix may be discontinued. Surrounding the helix and extending a distance beyond it, as required, is a dissipative jacket comprising a cylinder-like casing having an inside surface contiguous with the outermost part of the helical conductor. When the pitch is small, substantially all of the wall current associated with the circular electric wave is conducted along the conductive helical path. A very small component of current is presented with a small reactance and resistance caused by the discontinuity between turns and the lossy material therebetween. It will not, however, appreciably affect the configuration of the TE_{01} mode. By gradually increasing the pitch of the helix, the component of current conducted by the helix is decreased whereas the component of current exposed to the lossy jacket increases. By controlling the manner in which the pitch varies, as will be described in detail hereinafter, the transition from low loss guide to high loss guide can be achieved with a minimum amount of spurious mode conversion.

Where the lossy section is a line termination, only one tapered helix is used. If the lossy section is an attenuator section inserted between two lengths of copper guide a pair of helices is used, one at each end, to couple the wave energy in and out of the attenuator.

These and other objects, the nature of the present invention, and its various features and advantages, will appear more fully upon more detailed consideration of the specific illustrative embodiments shown in the drawings and analyzed in the following detailed description of these drawings.

In the drawings:

Fig. 1 is a perspective view of a channel separating filter terminated in a mode matched attenuator in accordance with the invention;

Fig. 2 is a cut away view of the mode matched attenuator shown in Figure 1; and

Fig. 3 is a cut away view of an attenuator section matched at both ends.

Referring more specifically to Fig. 1, there is shown a channel separating filter as might be found at a repeater station in a long distance communications system in which a plurality of TE_{01} circular electric mode waves are selectively separated by transferring them into dominant mode TE_{10} signals. Entering the filter along circular waveguide 10 are three modulated signals at frequencies f_1 , f_2 and f_3 . The signals are received in the circular electric TE_{01} mode, that being the mode in which energy is most efficiently transmitted between distant repeater stations. However, since the TE_{01} circular mode is not the mode usually utilized directly in the components of such a station, the frequency selective coupled wave transducers 11, 12 and 13 are employed to separate the channels and convert them to the TE_{10} mode.

The filter is terminated by a lossy section of waveguide 14 to dissipate any residual signal not extracted by transducers 11, 12 and 13, thus avoiding reflections which may cause distortion or other harmful effects within the system.

To avoid the conversion of the circular electric TE_{01} mode to higher order circular electric modes or spurious non-circular electric mode which would be generated and reflected back, notwithstanding the line termination, as a result of the change in transmission constants between the low loss copper guide of section 15 and attenuator 14,

the transition from the one to the other must be gradual and made in such a manner as to match the normal mode configurations in the two transmission media.

Fig. 2 shows in detail the construction of an attenuator embodying the principles of the invention. The section of circular waveguide 15 corresponds to the section 15 of Fig. 1. Guide 15 is a solid wall low loss guide of diameter d . This diameter must be greater than the critical or cut-off diameter for the TE_{01} mode being transmitted in the guide. The cut-off diameter is equal to $1.22\lambda_0$, where λ_0 is the wavelength in free space of the longest wave being transmitted therethrough. In practice, d might be anywhere from 1.25 to 10 times the cut-off diameter, depending upon the particular application.

Directly adjacent to guide 15 is the attenuator section 14, corresponding to the line terminating section 14 of Fig. 1. Section 14 comprises the tapered helix 20, the dissipative casing 21 and the conductive shield 23. Casing 21 may be made of machined carbon or any suitable plastic or dielectric material, such as polyethylene, in which small particles 22 of resistive material, such as iron dust or carbon black, are suspended. Alternately, casing 21 may be constructed as disclosed in my copending application Serial No. 679,835, filed jointly August 23, 1957, with G. T. Kohman, S. E. Miller and J. A. Young, Jr. As therein described, the lossy jacket comprises strands of dielectric material that are coated with a thin metallic semiconductive or resistive film and then laminated with a suitable dielectric plastic. In particular, fibrous glass material is coated with a thin metallic oxide and then laminated with a synthetic resin such as epoxide.

Casing 21 is covered with a non-corrosive conductive shield 23 which serves to protect the line from outside mechanical influences such as weather, moisture and insects and from electrical influences such as lighting or stray radiation from adjacent transmission lines.

Located within casing 21 is the conductive member 20 wound in a substantially helical form of varying pitch. Conductor 20 may be solid or stranded and may comprise a base metal such as iron or steel plated by a highly conductive material such as copper or silver. Adjacent turns 24 and 25 of the helix are electrically insulated from each other by either leaving a small air gap 26 between adjacent turns when bare wire is used, or by using enameled or plastic insulated wire. As the space between adjacent turns increases, due to the increasing pitch, the air space may be relied upon for the necessary insulation.

At the junction of guide 15 and attenuator 14, the helix is close wound, consistent with the above-mentioned insulation requirements. The distance between turns in any event must be less than one-quarter wavelength and is preferably such that the gap 26 between adjacent turns is less than the diameter of conductor 20. The inside diameter of the helix is equal to the diameter d of guide 15 and in all respects appears electrically as a continuation of the low loss guide in the immediately adjacent region.

As helix 20 extends away from guide 15 the space between successive turns increases with each successive turn until the space therebetween is greater than one-half wavelength of the lowest frequency to be attenuated. The longitudinal extent of helix 20 is represented in Fig. 2 as l and is between one-half to one beat wavelength, a beat wavelength being defined as

$$\lambda_b = \frac{\lambda_2 \lambda_1}{\lambda_2 - \lambda_1}$$

where λ_1 is the wavelength of the exciting mode and λ_2 is the wavelength of the incipient spurious mode to be suppressed. For example, λ_1 will be the wavelength of the TE_{01} mode and λ_2 the wavelength of the TE_{02} mode. Where there are several offending spurious modes, the longest beat wavelength must be used.

In operation, the circular electric TE_{01} wave being

transmitted along guide 15 will be excited within helix 20 as the wave enters the attenuator section. In the close wound region immediately adjacent to guide 15 the major component of the circular current associated with this mode is conducted along the helical path by each turn. Since the pitch is small, this component constitutes substantially the entire current of the wave. A very small component of the wave is presented with a small impedance caused by the discontinuity between adjacent turns. This impedance will have the effect of changing the transmission constant of the medium, as seen by the wave, very slightly, and the transition from guide 15 to attenuator 14 will not affect the field configuration to any substantial degree.

As the pitch increases, less and less of the path traveled by the circular current will be through the conductive member 20 and more and more through the dissipative jacket 21. As the nature of the current path changes, the effective transmission constant of the transmission path changes. The effect of helix 20 might be likened to an aperture which is slowly opened, allowing more and more of the dissipating effect of the resistive casing to become effective. By extending the aperture opening over a length equal to from one-half to one beat wavelength, moding is reduced to a tolerable level within a reasonably short distance.

Beyond the helix, attenuation takes place at a uniform rate until all incident energy is dissipated. The overall length L of section 14 will vary with the requirements of the particular system, being greater, of course, where more energy is to be dissipated.

Fig. 3 is illustrative of an attenuator to be interposed between a pair of low loss circular waveguides 30 and 31 to partially attenuate a TE_{01} circular electric signal rather than to completely dissipate it as in the application described above with reference to Fig. 2. The embodiment of Fig. 3 is essentially a pair of units disclosed in Fig. 2 placed back to back.

Wave energy entering the attenuator 32 from guide 30 is guided along helix 35 for a distance l corresponding to between one-half to one beat wavelength. Beyond this distance and until the second helix 36 is reached, the wave energy is fully exposed to the dissipative jacket 33. As the wave enters upon the region occupied by helix 36, the latter is energized and gradually guides the wave along to guide 31. By decreasing the pitch of helix 36 in the same manner as the pitch of helix 35 increased, there is a gradual transition back to the low loss guide 31. The overall length L' of attenuator 32 is a function of the desired attenuation. Units having different attenuations, i.e., 10 db, or 20 db attenuators, may be made and calibrated and used as required. To protect the attenuator and prevent radiation therefrom, a conductive shield 34 is placed around the lossy jacket 33 and extends between guides 30 and 31.

In all cases it is understood that the above-described arrangements are illustrative of a small number of the many possible specific embodiments which can represent applications of the principles of the invention. Numerous and varied other arrangements can readily be devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. Means for coupling TE_{01} mode circular electric wave energy between transmission media having different transmission characteristics comprising at least one section of transmission line having a first transmission constant for said TE_{01} mode wave energy, a second section of transmission line having a second transmission constant for said TE_{01} mode wave energy and means for coupling said lines comprising at least one elongated member of conductive material wound within said second line in a substantially helical form of continuously varying pitch.
2. In a multimode electromagnetic wave transmission

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system means for generating and means for utilizing TE₀₁ circular electric wave energy, low loss transmission means for transmitting said wave energy between said generating and said utilizing means, and means for attenuating said TE₀₁ mode wave energy comprising a section of lossy transmission line coupled to said transmission means by at least one elongated conductive member wound within said lossy line in a substantially helical form having progressively increasing spaces between successive turns.

3. An attenuator for terminating an electromagnetic transmission line comprising an end enclosed hollow cylindrical section of dissipative material surrounding an elongated member of conducting material wound in a substantially helical form extending longitudinally from the open end of said section toward the closed end and having a progressively increasing pitch, said member terminating when the space between successive turns has increased to approximately one-half wavelength of the lowest frequency wave energy to be attenuated, and a conductive shield covering said section.

4. The combination according to claim 3 wherein said helix extends longitudinally along said section from between one-half to one beat wavelength where a beat wavelength λ_b is defined as

$$\lambda_b = \frac{\lambda_2 \lambda_1}{\lambda_2 - \lambda_1}$$

λ_1 being the wavelength of the exciting mode and λ_2 being the wavelength of an incipient spurious mode to be suppressed.

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5. An attenuator for TE₀₁ mode circular electric wave energy comprising a hollow cylindrical section of dissipative material surrounding a pair of conductively insulated helical members, each of said helices extending longitudinally from an end toward the center of said section and having a progressively increasing pitch, said helices terminating when the space between successive turns has increased to approximately one-half wavelength of the lowest frequency to be transmitted therethrough, and a conductive shield covering said section.

6. The combination according to claim 5 wherein said helices extend longitudinally along said section from between one-half to one beat wavelength where a beat wavelength λ_b is defined as

$$\lambda_b = \frac{\lambda_2 \lambda_1}{\lambda_2 - \lambda_1}$$

λ_1 being the wavelength of the exciting TE₀₁ mode and λ_2 is the wavelength of an incipient spurious mode to be suppressed.

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